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Economic Sustainability and Riskiness of Cover Crop Adoption for Organic Production of Corn and Soybean in Northern Italy

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Abstract: Techniques based on terminated cover crops are proposed in organic agriculture instead of traditional inter-row tillage for weed control in subsequent grain crops. We estimated the profitability and evaluated the riskiness of novel techniques compared to the traditional one. Two-year yield data from three on-farm trials for corn and one for soybean in northern Italy were combined with cost and revenue data to calculate and compare gross margin distributions of different techniques in each crop. The relative ranking of techniques and the associated riskiness was assessed by these distributions using the stochastic dominance principles. Corn yield response on cover crop-based treatments was very variable, making the adoption of cover crops overall less sustainable from an economic point of view than the traditional tillage-based technique. Further research in this sense was nonetheless warranted by observed exceptions. Hairy vetch cover crop tended to higher profitability and lower riskiness than crimson clover for subsequent corn cropping. Specific analyses suggested nil or slightly negative nitrogen fertilizer effects of legume residues on corn. Results indicated that profitability could be maintained with cover crops in soybean compared to the traditional practice. In particular, triticale tended to provide better economic performances than inter-row tillage.

Keywords: cover crops; economic viability; nitrogen availability; organic farming; riskiness; stochastic dominance

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1. Introduction

Agriculture is committed to enhance its economic, agronomic and environmental sustainability. Organic agriculture and conservation agriculture are two facets of a strategy meant to achieve this aim. The organic livestock sector is growing steadily in Europe, where organic cattle, pig and poultry productions show annual growth rates ≥5% [1] and require, therefore, a growing amount of organic feed. The dairy cattle livestock system typical of the northern Italian plain heavily relies on corn (*Zea mays* L.) as the main energy feed and on soybean (*Glycine max* L. (Merr.)) as the most important feed protein source. These crops are equally important for conventional and for organic dairy livestock systems in the region.

In organic farming, a proper management of weeds is mandatory in order to achieve successful crop yields. Tillage with repeated passes of inter-row cultivation equipment is a typical practice for weed control under organic farming of wide-row crops such as corn and soybean. However, frequent soil cultivation can have environmental and economic effects on the sustainability of farming systems [2,3].

In recent decades, practices such as the integration of cover crops into crop rotations have been proposed to mitigate the effects of frequent tillage [4], implementing the above-mentioned complementation between organic farming and conservation agriculture in what is termed as cover crop-based no-tillage or reduced tillage [5]. Schipanski et al. [6]

displayed nutrient retention benefits that occurred primarily during cover crop growth, weed suppression benefits that occurred during cash crop growth through a cover crop legacy effect and soil carbon benefits that increased slowly over time. A strategy based on roller crimper-terminated cover crop mulches (legumes or cereals) is spreading as a tool of weed control for the subsequent grain crops [7–9].

Research on cover crop-based no-tillage or reduced tillage in organic farming is still limited in Europe [5]. The few assessments of this technique in Italy were restricted to vegetable organic cropping [10,11]. Conversely, several trials were reported from the USA and these investigations addressed a wide range of practical questions, including the profitability of cover crop-based practices compared to the traditional ones [5]. Although potentially useful, innovative cropping practices may not be indeed unquestionably accepted by farmers. The economic impact of their introduction has been identified as the strongest incentive to adopt cover crops [12], making the economic assessment of those practices advisable [13,14]. The aim of the current study is to assess the economic sustainability and riskiness of novel techniques based on terminated cover crop mulches for the organic cultivation of corn and soybean taking northern Italy as a case study.

2. Materials and Methods

2.1. Field Trials

Farm experiments were performed over two consecutive cropping seasons (2016–2017 and 2017–2018) in the Lombardy region, northern Italy. Three corn trials were established in each season in as many organic farms located in Malagnino, Nuvolera and Roverbella, respectively. The farm in Roverbella also hosted a soybean trial in both seasons. Two legume species, namely, crimson clover (*Trifolium incarnatum* L.) and hairy vetch (*Vicia villosa* Roth), were used as autumn-sown, spring-terminated cover crops in the corn trials, and two cereals, namely, rye (*Secale cereale* L.) and triticale (×*Triticosecale* Wittm.), were used in the soybean trial. The experiments were laid according to a randomized complete block design with four replications, with plots 5.6 m wide and 10 m long (56 m^2), including eight rows 70 cm apart.

Details on the agronomic management of cover and cash crops are summarized in the Supplementary Table S1, while termination methods and cash crop sowing techniques are summarized in Supplementary Table S2. To assess the N fertilizer effect of cover crops on corn, a minimal nitrogen fertilization of 40 kg N/ha was applied at sowing. This fertilizer rate was estimated following a surface N balance model that quantifies the amount of plant N derived from soil, atmosphere and fertilizers [15]. In addition to the plots of the cash crop sown on terminated cover crops, each block also included a check plot, where the cash crop was sown on tilled soil and weeds were controlled after the crop establishment by one inter-row cultivation. This check treatment was termed as 'inter-row weeding' (IRW) and later compared for agronomic and economic performance to the cash crop grown following the cover crops.

2.2. Agronomic Evaluation

Corn and soybean grain yield were recorded at maturity by harvesting the four central rows of each plot, corresponding to an area of 28 m^2. The harvested grains were dried to a constant humidity of 13%, winnowed and weighed.

The total above-ground biomass (AGB) including cover crops and weeds was determined at the time of cover crop termination by harvesting two areas of 0.25 m^2 per plot. Samples were dried at 60 °C until constant weight to calculate the dry matter (DM) content separately for cover crops and weeds.

In the second season and only for the corn trials, total AGB (cover crops plus weeds) was analyzed for total C and N content by the dry combustion method using a ThermoQuest NA1500 elemental analyzer (Carlo Erba, Milano, Italy). Prior to the analysis, samples were ground with a rotary-knife mill equipped with a sieve of 4 mm mesh; thereafter an aliquot was ground with a ZM 100 centrifugal mill equipped with a sieve of 0.2 mm mesh

(Retsch Gmbh & Co., Haan, Germany). The apparent availability of N from cover crops (plus weeds) to corn was assessed by measuring the N accumulated by corn in the early vegetative stage (V7) and at harvest (R6) [16]. At each stage, corn plants were sampled from a total area of 1.4 m^2 per plot taken from the two outer rows of each plot side, and the dried samples were ground with the same equipment previously mentioned.

2.3. Economic Analysis

For each technique, the data for the construction of the economic analysis refer to: (i) list of the cultivation operations carried out; (ii) related costs (e.g., inputs, machinery and labor costs); and (iii) yield data from the experimental fields.

The cost of each cultivation operation was estimated using the machinery rental rates of each operation [17] plus the costs of the inputs (e.g., seed, irrigation). Rental rates were obtained based on local contractors' prices for the year 2018 [18]. These implicitly account for the cost of fuel, labor, interests and depreciation on equipment used for each operation. All the estimated operational costs are reported in Supplementary Table S3.

The revenues from the cash crops were obtained by multiplying the yield data (in t/ha) from field trials by the average prices of the years 2017 and 2018 at the market of Milan [19]. Common Agricultural Policy support was also included in the revenues. Crop revenues for all treatments, locations and years are reported in Supplementary Tables S4 and S5.

The unitary gross margin (GM) for each technique was computed as revenues from the cash crop minus direct cropping costs per hectare cultivated. While cropping costs were the same for each location, year and crop (i.e., corn or soybean), this was not the case for revenues, because of the recorded different yield levels. Hence, the gross margin is stochastic in nature as shown in the following formula:

$$\widetilde{GM_{i,t}} = \widetilde{R_{i,t}} - TC_i \tag{1}$$

where $\widetilde{R_{i,t}}$ are the revenues, TC_i are direct crop-specific costs associated to the ith crop technology/location in the tth year and the tildes identify what is assumed to be a stochastic variable. $\widetilde{R_{i,t}}$ is derived by multiplying crop yields and prices that, in principle, should be considered both stochastic in nature. However, the present analysis focuses only on the comparison of GM of the techniques used on the same crop (i.e., corn techniques and, separately, soybean techniques). As a result of the fact that the distribution of the price is the same for all techniques in each crop, the distributions of the GM in the empirical analysis are obtained accounting for the distribution of yields of each technique but using the average price of the considered product. As anticipated, $\widetilde{R_{i,t}}$ includes the European Union (EU) Common Agricultural Policy (CAP) support provided in the form of decoupled direct payments (a given amount of Euro granted to each farmer on the basis of the amount of eligible land to support the farm income) and of agro-environmental payments granted within the EU Rural Development Policies to support organic production. The CAP support is included in the economic analysis because it affects the riskiness of the crop activities being a relatively stable and not negligible share of the farm revenues [20].

The GM seems to be the most suitable index to compare the economic performances of different cropping techniques because, not including fixed or overhead costs, it is not affected by the specific structure of the farm [21].

Large series of gross margin were obtained by using the Bootstrap technique, that is, a resampling method (a random sampling with replacement) that is used to do inference about a population from sample data [22]. The basic idea is that the observed sample contains all the available information about the underlying distribution and, hence, resampling the sample is the best guide to what can be expected from resampling from the distribution. Moving from the four experimental data (replication values) of each technique, 10,000 random iterations were created using the software R [23] for each crop technique, location and year. A nonparametric ordinary resampling bootstrap has been used relying on a sample that has the same size as the original dataset [22]. In particular, we bootstrapped the gross margins obtained from the trials and the outcomes are used to calculate the moments of these distributions and to represent them in terms of probability density function. These were described using mean (μ), coefficient of variation (CV) and skewness. The mean was used to compare the average profitability among different locations and techniques. Coefficient of variation and skewness were used to preliminarily assess the risk associated with each technique. Specifically, the CV is a simple measure of risk because it measures the width or spread of a distribution. As the riskier condition has a wider range of potential outcomes, wider distributions are usually associated with greater risk. However, this index does not focus on the left tail of the distribution, which is the part of the distribution that matters in risk analysis. This is a severe limitation for non-symmetric distributions. To overcome this problem, the degree of skewness was also estimated to reveal insights about the probability of negative results.

To account both for average profitability and riskiness of the considered techniques, the stochastic dominance approach [24] was applied. This is a form of non-parametric stochastic ordering that enables to rank one probability distribution of outcomes (x) as superior to another distribution [25]. The most convenient way to represent continuous probability distributions is using cumulative distribution functions (CDFs) that are computed ordering the outcome from the lowest to the highest levels of outcome (GM per hectare in our case) [26]. In this study, the risky alternatives correspond to the different crop techniques. To rank the different risky alternatives, second-degree stochastic dominance (SSD) was used. This requires the assumption that decision-makers must be risk-averse for all values of x [24] but this principle applies also for very low levels of risk aversion. Under SSD, the dominance between two risky alternatives A and B is established considering the areas below the CDF as follows:

$$\int_{-\infty}^{x^*} F_A(x)dx \leq \int_{-\infty}^{x^*} F_B(x)dx \text{ for all values of } x^* \quad (2)$$

This means that alternative A is dominant over B if the curve of the cumulative area under the CDF for the dominant alternative (i.e., $F_A(x)$) lies everywhere below and to the right of the corresponding curve for the dominated alternative (i.e., $F_B(x)$) [24]. Hence, the alternative chosen by a risk-averse decision maker will have a smaller area under the CDF for all possible outcomes of x. As we move from the lowest to the highest outcome, this selects the alternative that performs better for the worst outcomes that are those a producer would like to avoid (i.e., low GM in our case). The SSD principle (2) requires that, for low outcomes, the CDF of the dominant alternative lays above the other. In our case, this simply means that the probability of obtaining an arbitrarily chosen small level of GM is lower than for the dominated alternative. This criterion allows that the selected alternative performs less well than the dominated alternative for high outcomes. This means that the CDF of the selected activity can lay below the dominated alternative but only for outcomes higher than a given level. However, the SSD principle (2) weights both aspects using the sum of the area below the CDF. This ensures that the poor performance of the selected activity experienced for high levels of outcomes is never large enough to countervail its good performance for low levels of outcomes.

3. Results

3.1. Corn

Corn yield was variable among treatments and among farms in the first year. The corn grown on the cover crops had higher yield in Malagnino, substantially similar yield in Nuvolera and lower yield in Roverbella compared to the check treatment (Table 1).

Table 1. Mean grain yield (t/ha) of corn in three organic farms (Roverbella, Nuvolera, Malagnino) and two evaluation years.

Location [a]		Roverbella	Nuvolera	Malagnino
Harvest 2017				
Hairy Vetch	Rolled	1.87 b	5.53 a	4.21 a
Crimson Clover	Rolled	1.81 b	4.37 a	5.00 a
Inter-row Weeding		3.78 a	4.80 a	2.33 b
Harvest 2018				
Hairy Vetch	Rolled	2.78 ab	-	3.56 b
	Shredded	2.23 ab	3.31 a	1.67 c
Crimson Clover	Rolled	-	-	1.32 c
	Shredded	1.99 b	1.63 b	0.85 c
Inter-row Weeding		4.09 a	3.47 a	5.24 a

[a] In each location and year, except Nuvolera 2017, the variation among treatments was significant at $p \leq 0.05$ according to F test of ANOVA, and mean values followed by different letters were different at $p \leq 0.05$ according to Tukey's studentized range (HSD) test. For Nuvolera 2017, ANOVA was not used because of heterogeneity of variances, and the variation among treatments was tested by the non-parametric Kruskal–Wallis test, whose χ^2 value was not significant at $p \leq 0.05$.

Although still in the presence of a certain variation among treatments from farm to farm, the yield data of the second year clearly emphasized the advantage of the traditional inter-row weeding (check treatment) over any cover crop technique (Table 1). Exception to this trend was the corn grown after the hairy vetch in Nuvolera, which yielded as much as the check. Results of corn N uptake at harvest in the second year reflected the trend observed for grain yield (Supplementary Table S6). During the early vegetative growth in 2018, the corn following cover crops accumulated significantly less N than in the inter-row weeding treatment at Malagnino and Nuvolera, while corn in both rolled and shredded hairy vetch treatments took up more N than in the check treatment at Roverbella (Supplementary Table S6). A different figure was obtained with corn at physiological maturity, when the treatments did not differ from each other in all farms, except for the corn grown on the shredded crimson clover that tended to accumulate less N in each location (Supplementary Table S6).

The total AGB of cover crops plus weeds at termination ranged from 4.1 to 10.2 t/ha DM (Table 2) and, except at Malagnino in spring 2017, it did not differ among treatments in both years and all farms.

Table 2. Total above-ground biomass (total AGB) of cover crop plus weeds and proportion of cover crop in total AGB of autumn-sown, spring-terminated cover crops in three organic farms of northern Italy (Roverbella, Nuvolera, Malagnino) and two evaluation years (2017, 2018) with N content, C/N ratio and N uptake of total AGB recorded in the second year.

Year	Location	Cover Crop	Total AGB (t DM/ha)	Cover Crop Proportion (%)	N Content (g N/100 g DM)	C/N (g/g)	N Uptake (kg N/ha)
Spring 2017	Malagnino	Hairy vetch	4.4 b	85.8 a	-	-	-
		Crimson clover	6.1 a	44.4 b	-	-	-
	Nuvolera	Hairy vetch	4.3 a	97.6 a	-	-	-
		Crimson clover	4.5 a	87.6 a	-	-	-
	Roverbella	Hairy vetch	5.0 a	57.2 a	-	-	-
		Crimson clover	6.1 a	19.4 b	-	-	-
Spring 2018	Malagnino	Hairy vetch	5.6 a	42.0 a	3.1 a	12 b	174 a
		Crimson clover	6.0 a	34.8 a	2.3 b	17 a	137 b
	Nuvolera	Hairy vetch	5.4 a	75.2 a	3.7 a	11 b	200 a
		Crimson clover	4.1 a	68.1 a	2.8 b	14 a	110 b
	Roverbella	Hairy vetch	8.3 a	58.3 a	3.5 a	11 b	294 a
		Crimson clover	10.2 a	17.1 b	1.8 b	22 a	184 b

Within each location and year, mean values followed by different letters were significantly different at $p \leq 0.05$ according to F test of ANOVA.

Conversely, the fraction of the whole biomass represented by the cover crop was 2.0–3.4 times significantly higher for hairy vetch compared to crimson clover at Malagnino in spring 2017, and at Roverbella in both years (Table 2). In the second year (2018), late frosts at the beginning of spring caused some damage to the legume cover crops, resulting in gaps in the vegetation and an increase in weed biomass (Table 2). In spring 2018, total AGB residues were always significantly richer in N and had a lower C/N ratio in the hairy vetch treatment (C/N = 11–12) compared to the crimson clover treatment (C/N = 14–22) (Table 2). At the same time, significantly more N (from +37 to +110 kg N/ha) was supplied to soil with AGB residues in the hairy vetch treatment (Table 2).

The introduction of cover crops led to an increase in production costs compared to the traditional organic method across the two years of study (Supplementary Table S3). The relative costs are comparable since the operations were carried out in the same way in the three locations throughout the two years. The high cost of the vetch seed made this crop the most expensive one (about +16% compared to IRW), both with rolling and shredding termination options. Merely looking at the costs, the rolled crimson clover would seem the most appealing option for growers approaching the cover crop technique, with a cost increase of about +11% compared to the traditional technique. Averaged across cover crops, termination by shredding would imply greater cost increases (about +15%) than rolling (about +11%).

Following the previously described grain yield data, results of crop revenues were very inconsistent in the year 2017 (Supplementary Table S4). The possible advantage of alternative techniques was in fact location-dependent, with cover crops reducing crop revenues only in one location (Roverbella), while giving relatively high corn revenues with rolled hairy vetch in Nuvolera and rolled crimson clover in Malagnino. Unlike in the first year, cover crops resulted in lower crop revenues compared to IRW in all locations in 2018 (Supplementary Table S4). Differences were large in two locations out of three (Roverbella and Malagnino), with about or more than 500 €/ha loss in crop revenue. The results were particularly negative with crimson clover, especially when shredded. The only partial exception to this trend in 2018 was represented by the cover crop with hairy vetch in Nuvolera (which was only shredded in that location in 2018), whose average crop revenue was only slightly lower compared to the IRW treatment (Supplementary Table S4). A word of caution is needed when interpreting the revenues because the corn price levels observed in 2017 and 2018 were slightly higher than the average values in the previous years. Hence, the results should be evaluated keeping this aspect into consideration.

Gross margins (GM) in 2017 differed among locations, but at least one cover crop had higher gross margin than the IRW technique in Malagnino and Nuvolera (Table 3). Based on these results, both rolled hairy vetch and crimson clover could be equally suggested as cover crop in organic crop production. However, the adverse weather conditions and the severe weed competition in the autumn 2017-spring 2018 season caused a general drop in production compared to the previous year. During the 2018 trials, therefore, the traditional technique of weed control outperformed the cover crops used in all the locations also in terms of GM (Table 3).

The riskiness associated to the different techniques was assessed, as mentioned, using coefficient of variation (CV) and skewness of the gross margin distributions. In 2017, the two cover crops had a lower relative variability (as CV) of GM than the traditional IRW technique (Table 3). According to this coefficient, both cover crops had lower economic risk compared to the traditional technique. Among the cover crops, crimson clover had smaller relative variability, but this was always accompanied by a positive skewness, which meant a higher probability of achieving small gross margin. A system based on crimson clover could then be an option for a farmer to reduce the risk associated with a wide variability from the IRW technique, but the possibility that this cover crop might give small GM should not be overlooked.

The inter-row weeding technique had a limited relative gross margin variability in 2018 (Table 3). Nonetheless, some cover crops in Nuvolera and Malagnino had levels of relative variability similar to those of the inter-row weeding technique (Table 3). The skewness level of IRW was negative in two out of three locations, indicating its high chance of achieving positive economic results. Shredded hairy vetch showed negative skewness only in one location. In general, using only the CV, it was not possible to state whether any cover crop allowed a reduction of the gross margin risk in comparison with the traditional technique. However, the obtained values of skewness suggested that the inter-row weeding is a low-risk technique.

Table 3. Mean gross margin (€/ha), riskiness as coefficient of variation (CV) and skewness (Skewn.) of the gross margin of corn crop in three organic farms of northern Italy (Roverbella, Nuvolera, Malagnino) and two evaluation years. Based on economic data and elaborated from the field experiment cumulative distribution obtained by 10,000 bootstrap random iterations from gross margin data.

Location [a]		**Roverbella**			**Nuvolera**			**Malagnino**		
		Mean	CV	Skewn.	Mean	CV	Skewn.	Mean	CV	Skewn.
Harvest 2017										
Hairy Vetch	Rolled	–414 c	–0.17	–0.51	1010 a	0.11	–0.56	624 b	0.11	–0.56
Crimson Clover	Rolled	–369 b	–0.06	0.05	641 c	0.06	0.44	985 a	0.06	0.44
Inter-row Weeding		552 a	0.27	–0.48	934 b	0.34	–0.40	120 c	0.34	–0.40
Harvest 2018										
Hairy Vetch	Rolled	82 b	1.19	0.27	-	-	-	260 b	0.32	0.004
	Shredded	–183 c	–1.31	0.08	112 b	0.98	–0.03	–495 c	–0.12	–0.13
Crimson Clover	Rolled	-	-	-	-	-	-	–501 c	–0.20	–0.39
	Shredded	–196 c	–0.47	–0.03	–441 c	–0.10	0.03	–731 d	–0.16	0.05
Inter-row Weeding		552 a	0.27	–0.48	934 b	0.34	–0.40	120 c	0.34	–0.40

[a] In each location and year, mean values followed by different letters were different at $p \leq 0.05$ according to Wilcoxon–Mann–Whitney test.

Figure 1A shows the gross margin CDF for the first year of trials (2017) and for the three locations.

The stochastic dominance (SD) was used to compare the traditional weed management system (IRW) with cover crops. The results of the SD analysis provided mixed outcomes in this year. While inter-row weeding outperformed all cover crops in Roverbella, in the other two locations (Nuvolera and Malagnino) some cover crops dominated IRW (Table 4).

Table 4. Matrix [a] with ranking level of gross margin second-degree stochastic dominance of corn crop in three organic farms (Roverbella, Nuvolera, Malagnino), year 2017. Based on economic data and elaborated from the field experiment cumulative distribution obtained by 10,000 bootstrap random iterations from gross margin data.

		Inter-Row Weeding	**Hairy Vetch**	**Crimson Clover**	**Dominance Ranking Level**
			Rolled	**Rolled**	
Roverbella					
Inter-row Weeding		.	+ (FD)	+ (FD)	1
Hairy Vetch	Rolled	− (FD)	.	−	3
Crimson Clover	Rolled	− (FD)	+	.	2
Nuvolera					
Inter-row Weeding		.	−	?	
Hairy Vetch	Rolled	+	.	+ (FD)	1
Crimson Clover	Rolled	?	− (FD)	.	
Malagnino					
Inter-row Weeding		.	− (FD)	− (FD)	3
Hairy Vetch	Rolled	+ (FD)	.	− (FD)	2
Crimson Clover	Rolled	+ (FD)	+ (FD)	.	1

[a] For each combination row × column, the symbols (+ and −) mean that: row heading dominates (+) or is dominated by (−) column heading. FD = first degree stochastic dominance; ? = no dominance can be identified.

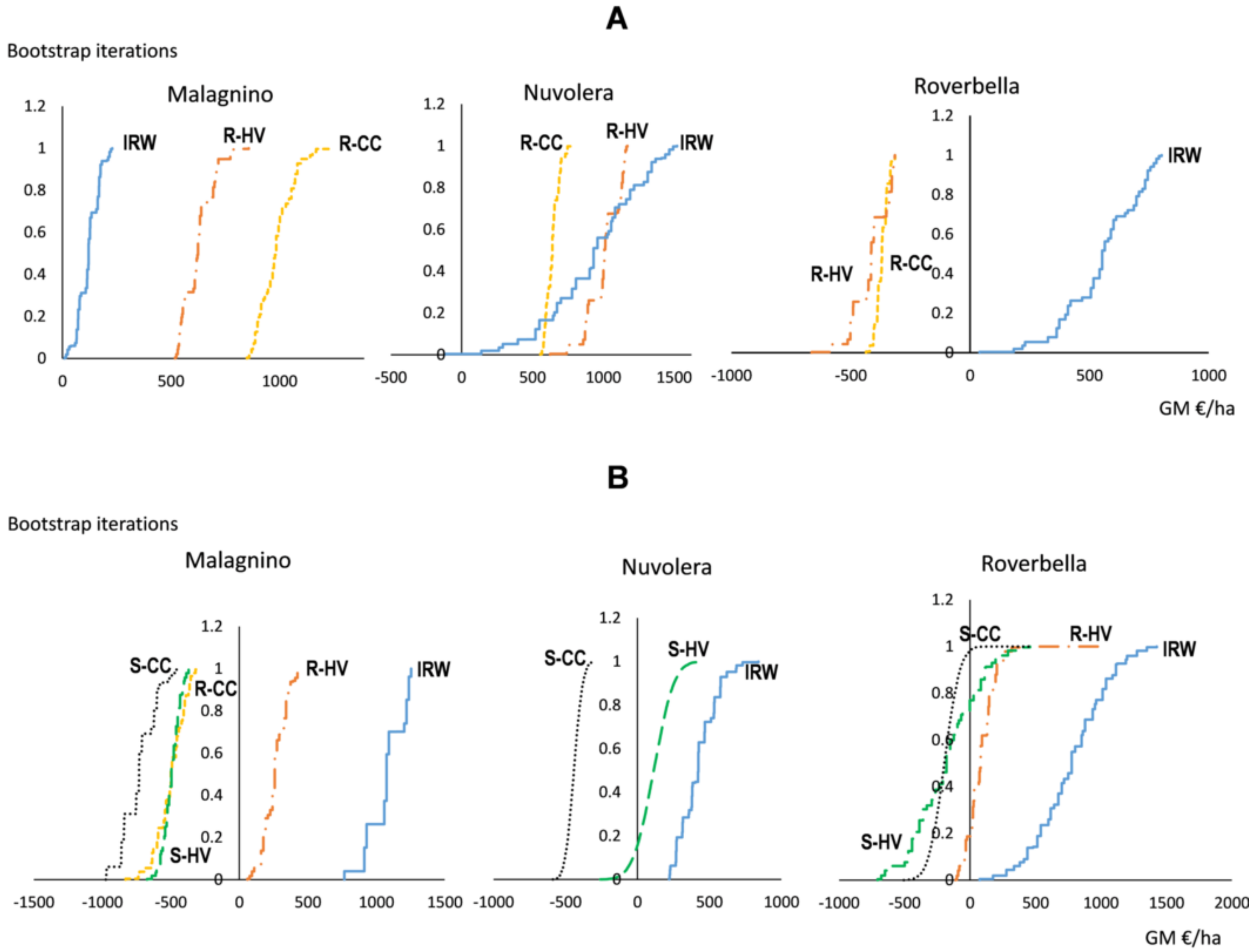

Figure 1. Cumulative distributions of gross margins (GM) for corn in three organic farms of northern Italy (Malagnino, Nuvolera, Roverbella) and two evaluation years (2017, 2018). Based on economic data and elaborated from the field experiment cumulative distribution obtained by 10,000 bootstrap random iterations from gross margin data. (**A**) Corn in the first year in three locations; (**B**) corn in the second year in three locations. IRW: inter-row weeding; R-HV: rolled hairy vetch; R-CC: rolled crimson clover; S-HV: shredded hairy vetch; S-CC: shredded crimson clover; R-R-ST.

Hence, cover crops seemed a viable alternative to IRW in two out of three locations. However, no single cover crop outperformed the other. Hairy vetch was dominant in Nuvolera, while crimson clover was in Malagnino (Table 4). In the second year of trials (2018), the inter-row weeding technique dominated all the other considered weed-management systems (Figure 1B).

This result is very robust considering that it was obtained with the sole use of first-degree stochastic dominance. In contrast with the results of the previous year, one cover crop clearly outperformed the other. Rolled hairy vetch seemed to be the best cover crop because it dominated the other cover crop in all three locations (Table 5).

Table 5. Matrix [a] with ranking level of gross margin second-degree stochastic dominance of corn crop in three organic farms (Roverbella, Nuvolera, Malagnino), year 2018. Based on economic data and elaborated from the field experiment cumulative distribution obtained by 10,000 bootstrap random iterations from gross margin data.

		Inter-Row Weeding	Hairy Vetch		Crimson Clover		Dominance Ranking Level
			Rolled	Shredded	Rolled	Shredded	
			Roverbella				
Inter-row Weeding		.	+ (FD)	+ (FD)	n.a.	+ (FD)	1
Hairy Vetch	Rolled	− (FD)	.	+	n.a.	+	2
	Shredded	− (FD)	−	.	n.a.	?	3
Crimson Clover	Shredded	− (FD)	−	?	n.a.	.	3
			Nuvolera				
Inter-row Weeding		.	n.a.	+ (FD)	n.a.	+ (FD)	1
Hairy Vetch	Shredded	− (FD)	n.a.	.	n.a.	+ (FD)	2
Crimson Clover	Shredded	− (FD)	n.a.	− (FD)	n.a.	.	3
			Malagnino				
Inter-row Weeding		.	+ (FD)	+ (FD)	+ (FD)	+ (FD)	1
Hairy Vetch	Rolled	− (FD)	.	+ (FD)	+ (FD)	+ (FD)	2
	Shredded	− (FD)	− (FD)	.	?	+ (FD)	3
Crimson Clover	Rolled	− (FD)	− (FD)	?	.	+ (FD)	3
	Shredded	− (FD)	− (FD)	− (FD)	− (FD)	.	4

[a] For each combination row × column, the symbols (+ and −) mean that: row heading dominates (+) or is dominated by (−) column heading. FD = first degree stochastic dominance; ? = no dominance can be identified; n.a. = data not available.

3.2. Soybean

No difference in AGB at termination was observed between cover crops (>9.0 t/ha for both) in the first year, whereas rye produced higher AGB than triticale (10.8 t/ha vs. 8.9 t/ha, $p \leq 0.05$) in the second year. In both years, the proportion of the cereal cover crop over the total biomass exceeded 90%.

No statistically significant differences were found among treatments for soybean grain yield in both years (Table 6).

Table 6. Mean grain yield (t/ha) of soybean in one organic farm of northern Italy (Roverbella) and two evaluation years.

	Harvest 2017
Rye [b]	1.95 [a]
Triticale [b]	2.12 [a]
Inter-row Weeding	1.76 [a]
	Harvest 2018
Rye [b]	2.65 [a]
Triticale [b]	2.09 [a]
Triticale, SSR [c]	3.04 [a]
Inter-row Weeding	2.49 [a]

[a] In each year, the variation among treatments was not significant at $p \leq 0.05$ according to F test of ANOVA. [b] Soybean sown after strip tilling on rolled cover crops. [c] Soybean sod seeding on rolled cover crop.

However, a trend was evident, with soybean sown after the triticale cover crop showing a yield advantage of about 20% compared to soybean in the IRW treatment, either when it was sown after strip tilling on rolled triticale (2017) or when it was directly sown on triticale mulch by a sod seeder (2018). An excessive experimental error (field variability) likely prevented these differences to reach the $p \leq 0.05$ significance level.

The cover crop techniques led to an increase in production costs in comparison with the inter-row weeding technique also in soybean (Supplementary Table S3). The differences between rye and triticale cover crop costs are small but the soybean sod seeding on triticale mulch appears to be the best choice for a farm manager. Indeed, it shows the lowest relative increase in costs, namely, only a 10% increase in production costs in comparison with IRW, accompanied by the promising yield performance previously mentioned. The revenues relative to the cover crops were larger than those with the inter-row weeding technique in both years of trial (Supplementary Table S5). Among the cover crops, triticale had the best average revenue, in 2017 with soybean sowing after the strip tilling and in 2018 with soybean sod seeding on mulch.

The use of cover crops led to an increase of the gross margin in both years (Table 7).

Table 7. Mean gross margin (€/ha), riskiness as coefficient of variation (CV) and skewness (Skewn.) of the gross margin of soybean crop in one organic farm of northern Italy (Roverbella) and two evaluation years. Based on economic data and elaborated from the field experiment cumulative distribution obtained by 10,000 bootstrap random iterations from gross margin data.

	Mean	**CV**	**Skewn.**
	Harvest 2017		
Triticale [b]	558 [a]	0.12	0.12
Rye [b]	459 [b]	0.25	−0.02
Inter-row Weeding	496 [b]	0.22	0.46
	Harvest 2018		
Triticale [b]	889 [c]	0.05	0.23
Rye [b]	536 [d]	0.22	0.37
Triticale, SSR [c]	1027 [a]	0.15	−0.001
Inter-row Weeding	496 [b]	0.22	0.46

[a] In each year, mean values followed by different letters were significantly different at $p \leq 0.05$ according to Wilcoxon–Mann–Whitney test. [b] Soybean sown after strip tilling on rolled cover crops. [c] Soybean sod seeding on rolled cover crop.

Soybean sown on triticale after strip tilling in 2017 or on triticale mulch by sod seeding in 2018 achieved a higher gross margin than the inter-row weeding technique. The triticale cover crop technique had the lowest level of variability (CV) in comparison with the inter-row weeding technique (IRW) in both years (Table 7), hence suggesting that this cover crop reduced the riskiness of the crop. Even in 2018, triticale, that achieved the lowest gross margin, would be suggested as the least risky option. The results of the skewness level were inconsistent in the two years. The rye cover crop showed a negative skewness in 2017, while the triticale with soybean sod seeding did it in 2018 (Table 7). Thus, both cover crops seemed to be able of achieving good results in this regard.

Higher yields were generally recorded with the use of cover crops in this study. They compensated for the higher production costs compared to the traditional mechanical technique (Supplementary Table S3) in making the cover crops dominant according to the results of the SD, which suggested that one cover crop technique outperformed the traditional IRW technique in each year (Table 8; Figure 2).

In particular, the triticale cover crop dominated the IRW in both years, although only with soybean sod seeding in the second year (Table 8). Hence, the use of triticale appeared to be recommendable from an economic point of view. However, it is also clear that not all cover crop options ensure this result, as in both years the other cover crops were dominated by the traditional IRW (Table 8).

Table 8. Gross margin second-degree stochastic dominance matrix [a] with ranking level of soybean crop in one organic farm of northern Italy (Roverbella) in two evaluation years. Based on economic data and elaborated from the field experiment cumulative distribution obtained by 10,000 bootstrap random iterations from gross margin data.

	Inter-Row Weeding	Rye [b]	Triticale [b]	Triticale, Sod Seeding on Rolled Cover Crop	Dominance Ranking Level
			2017		
Inter-Row Weeding	.	+	−	n.a.	2
Rye [b]	−	.	−	n.a.	3
Triticale [b]	+	+	.	n.a.	1
			2018		
Inter-Row Weeding	.	+	+ (FD)	−	2
Rye [b]	−	.	+ (FD)	−	3
Triticale [b]	− (FD)	− (FD)	.	− (FD)	4
Triticale, Soybean Sod Seeding on Rolled Cover Crop	+	+	+ (FD)	.	1

[a] For each combination row × column, the symbols (+ and −) mean that: row heading dominates (+) or is dominated by (−) column heading. FD = first degree stochastic dominance; ? = no dominance can be identified; n.a.= data not available. [b] Soybean sown after strip tilling on rolled cover crops.

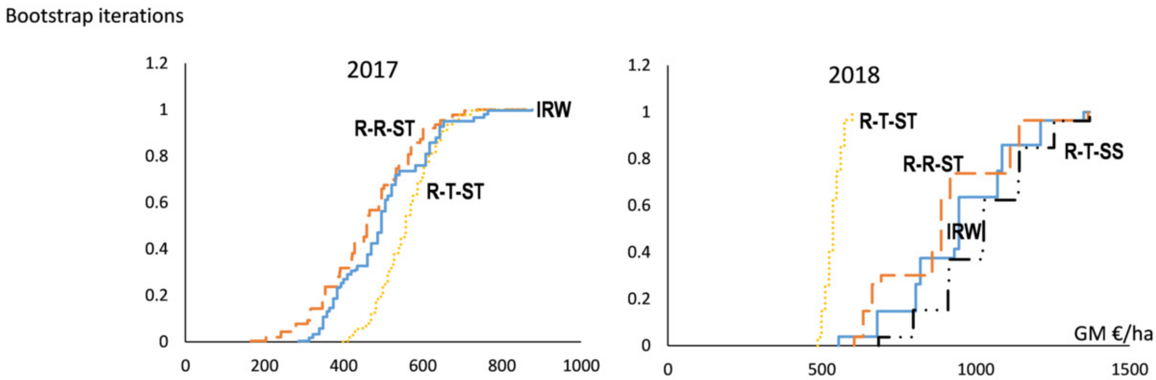

Figure 2. Cumulative distributions of gross margins (GM) for soybean in one organic farm (Roverbella) in two evaluation years (2017, 2018). Based on economic data and elaborated from the field experiment cumulative distribution obtained by 10,000 bootstrap random iterations from gross margin data. R-R-ST: rolled rye, and soybean sowing after strip tilling; R-T-ST: rolled triticale, and soybean sowing after strip tilling; R-T-SS: rolled triticale, and soybean sod seeding on cover crop mulch; IRW: inter-row weeding.

4. Discussion

4.1. Corn

A great variability of corn yield results following cover crops can be found in the literature, depending on local conditions, and ranging from almost complete yield failure to equal production compared to common tillage-based cropping [5]. Positive effects of legume cover crops on subsequent cash-crop yield have often been reported [27,28]. However, our results agree with those of other experiments that measured low or even negative effects of crimson clover and other legume cover crops on corn [29–31].

The low N fertilizer effect of hairy vetch and crimson clover residues were unlikely due to prolonged microbial N immobilization, given the quite low C/N ratios of the residues [32]. Instead, insufficient N provision by the cover crop to corn could be attributed to a lack of synchronization between N release from the cover crop and the corn N needs [5], favoring N losses in the environment. Hairy vetch residues were found to decompose fast in the soil, and, according to temperatures recorded in our trials, about 80% of cover crop N was likely released in 5–6 weeks after cover crop termination [33–35]. Studies conducted in laboratory demonstrated that also AGB of crimson clover decomposed fast, with most of the N being released in one month at 3 °C and 9 °C [36] and 22 °C [37]. In all the three locations and in both years, a consistent corn biomass was not established yet 4–6 weeks after cover crop termination (corn at V3–V6 stage) and, therefore, mineralized N could have been lost with leaching.

Another factor that can help explaining the low fertilizer effect of cover crops in our experiment is the competition of corn with weeds. The low C/N ratio that legume cover crops feature can cause a quick residue decay, thereby limiting the mulching effect for weed control [8]. In the second year, the gaps in the cover crop vegetation due to late frosts and the considerable delay of the corn sowing caused by the cold and rainy spring weakened the corn vigor and the mulching effect of cover crops, exacerbating, therefore, the competition exerted by aggressive weeds such as velvetleaf (*Abutilon theophrasti* Medik.) and rhizomatous Johnsongrass (*Sorghum halepense* (L.) Pers.). A greater weed biomass in corn was measured in Malagnino in the second year compared to the first one, whereas the weed biomass decreased in Nuvolera and remained constant in Roverbella (data not reported). The difficulty of growing corn with cover crop-based techniques is accentuated by the presence of challenging weeds. Mirsky et al. [38] indicated early emerging summer annual weeds and perennial weeds among the most difficult ones to be suppressed. With our weed array, common to observe in the target area but not trivial to handle, cover crops cannot be considered as the ultimate tool to solve the problem and their usefulness must be seen as a part of an integrated strategy of weed control, which must include also means such as crop rotations and false seedbed preparation.

Several studies have shown that even cover crops fixing large amounts of N cannot be relied upon as the sole source of N for a cash crop with high N requirements such as corn [12,39]. It is worth to mention, however, that cover crop cultivation between two consecutive corn seasons allows extracting N from the soil in a period characterized by high potential N leaching when rainfalls are frequent and abundant [40].

To some extent, the use of hairy vetch gave promising results for the subsequent corn yield. The interest on this winter legume as cover crop for cash crops is supported by a large literature evidence (e.g., [41–43]). Hairy vetch has been the most frequently studied legume cover crop, owing to its high levels of biomass and N release compared to other legume species, its winter hardiness and the good corn yield following its termination [5,12,44]. The reported lower fertilizer effect of crimson clover relative to other legume species including hairy vetch [29,45] could accentuate the lack of sufficient N for corn following this clover and account for the generally worse performance of corn cropped on crimson clover than on hairy vetch observed in our trials.

The present results also emphasized a general trend of better corn yield following rolling compared to shredding cover crops. Several termination techniques have been assessed in the literature, including different types of roller-crimpers, sickle bar mowers and flail choppers, suggesting that the choppers may result in limited soil cover and easier weed emergence caused by faster residue decay of small cover crop fragments and uneven distribution of the mulch on the soil surface [5].

With hairy vetch being a reliable cover crop option, the cover crop-based no-tillage or reduced tillage organic corn system remains challenging to adopt. A definite assessment of the economic sustainability of the use of cover crops for organic corn production was unfortunately hindered by the rather controversial results over the two years. This prevented the possibility of claiming unquestionably whether the cover crop techniques dominate (from an economic point of view) the traditional weeding technique in corn in all conditions. The greater production cost of the cover crop treatments compared to the traditional tillage (see Supplementary Table S3) negatively affected the economic performance of the cover crop treatments. The additional costs generated by the cover crops, largely caused by seed purchase and field management, ranged between 131 and 255 €/ha and were slightly higher than what is reported in the literature [46]. Literature estimates indicated a reduction up to over 50% of production costs for no-tillage practices compared to typical organic management contemplating repeated tillage for weed control [5]. Instead of a cover crop-based no-tillage system, however, we opted for a reduced tillage (strip tillage) approach in our trials, because of the unsatisfactory growth and yield results obtained in a pilot experiment in the same area with a no-till direct sowing of corn onto the rolled cover crops [47]. Furthermore, just one inter-row pass of rotatory hoe after corn establishment was sufficient to control weeds in the traditional tillage treatment of the current study, instead of the repeated passes envisaged in the literature estimates.

Yield can be a more important determinant of profitability than input costs [13,39].

However, although higher yields will be likely needed for a cover crop-based system to be as profitable as a conventional tillage-based system in the long-term, the adoption of cover crops has the potential to provide other indirect services [48]. These services are difficult to be valued economically, although they benefit not only the adopting farmers but the society at large [12]. Ecosystem services affecting, for instance, chemical, physical and biological soil properties should also be considered in assessing the profitability of alternative no-tillage or reduced tillage cropping systems. Although several studies have highlighted the economic and social benefits conferred by cover crop-based systems [5,12], literature on the economic evaluation of indirect benefits by cover crops is lacking.

To our knowledge, this was the first attempt in Europe to assess the prospects for adopting cover crop-based techniques in organic farming based on economic considerations. Alonso-Ayuso et al. [49] performed economic analyses on different cover crop termination options preceding a corn crop, but their study was carried out under conventional agricultural and also implied herbicide application beside roller crimping. The marked differences between the two years of trials in the current study did not provide a clear result in terms of associated riskiness, and it was not possible to univocally assess whether the cover crop technique has lower or higher level of risk than the traditional weeding technique. Nonetheless, the use of cover crops seems to increase the variability found (this was particularly evident in the second year) and, therefore, it is not a system to be suggested to a risk-averse farm manager. Previous evidence showed that promising results of cover crops for no-till corn cultivation could be prone to remarkable uncertainty due to, among other factors, great season-to-season variation in weed abundance [41,42].

4.2. Soybean

Although circumscribed to only one location in northern Italy, the adoption of cover crops seemed to be compatible with good yield in soybean. Acknowledging such a limitation of inference, our findings on soybean are nonetheless consistent with those on the agronomic performance of soybean sown onto terminated cereals reported in the USA [9,50]. Conversely, Champagne et al. [48] reported a rye-based, reduced-tillage soybean cropping to have lower input costs but also less profitability because of lower average yields than the tillage-based cropping.

The cost of soybean seed contributed noticeably to the production costs of this crop. Here we opted for higher soybean sowing rates compared to usual regional recommendations for organic soybean (ca. +25%). This is in line with suggestions made to obtain greater plant density and better yield in the presence of cover crop mulches, as well as hastening the soybean canopy closure and enhancing the weed control [5]. Production costs with the adoption of cover crops were higher than with the traditional tillage-based approach and, also for this crop, slightly higher than those reported in the literature [46].

The use of cover crops in this study generally provided higher yields of the cash crop than the traditional inter-row weeding, and the cover crop-based technique seemed to be a risk-reducing strategy for organic cultivation of soybean. The differences between rye and triticale in terms of soybean yield were small. However, triticale appeared to be the most recommendable option from an economic point of view, with either soybean sowing following a more expensive strip tilling or soybean sod seeding on mulches.

The sod seeding technique had the highest revenue in the case of soybean. Although this result should be considered with caution because it refers to one year of investigation only, the combination of triticale with the soybean sod seeding technique is an option worth of further assessment. We have also anecdotal evidence of one plot with soybean sod seeding onto rolled rye resulting in effective weed control and good grain yield. Literature evidence showed that soybean grown onto rolled cereals (mostly rye) could yield comparably with soybean planted into tilled soil [5]. However, appropriate equipment for cash crop planting into the cover crop mulch is essential for the success of cover crop-based no-tillage systems [5].

From these results, the organic soybean production seemed more likely to be economically sustainable with the use of cover crops than with the traditional approach. However, it is evident that a careful selection of the best performing cover crop species and technique is needed and further investigations on soybean are envisaged in the future to provide practical advice on how farmers should use the cover crops.

5. Conclusions

The paper assessed the economic sustainability and riskiness of novel techniques based on terminated cover crop mulches for the organic cultivation of corn and soybean taking northern Italy as a case study. Yield of corn and soybean under organic management entailing cover crop-based no-tillage or reduced tillage is severely challenged by different factors, such as weed presence and dynamics, optimal cover crop establishment, effective cover crop termination and successful cash crop establishment. Knowledge, skills and equipment are needed to tackle these challenges [5].

The present results were consistent overall with previous findings and suggested the positive economic effects of cover crops in organic soybean cultivation if the right cover crop technique is selected. In our analysis, the best results were obtained using triticale. Conversely, cover crops still appear as a questionable technique in corn, especially because of the increase in variability of yields, making it riskier than the traditional weed control technique. Therefore, producers are likely to consider carefully the adoption of cover crop-based systems. On the other hand, if cover crops are believed to generate positive indirect benefits (especially, environmental ones), it could be worth supporting their introduction by means of public incentives. If methods to decrease tillage in organic row crop production are sought to enhance soil conservation, 'green payments' are needed to offset possible yield reductions and economic losses [39]. Subsidies may be very important for promoting cover crop adoption in publicly supported conservation programs [12]. Two European policy measures could be envisaged to increase farmers' willingness to use cover crops. On the one hand, by introducing a specific payment within the agro-environmental schemes of the European Union's Rural Development Policy. On the other hand, by considering policy measures supporting the introduction of risk management tools such as farm insurances when the introduction of cover crops induces a sizeable increase of risk [12]. Based on the current results, these agricultural policy measures may be needed for corn (but not for soybean) because the higher risk will push insurance companies to ask premiums that are higher than in the case of traditional crop techniques and may then become not affordable for all producers.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/agronomy11040766/s1, Table S1: Summary of the cover crop and cash crop agronomic management for organic corn and soybean grown in two years across different farms in northern Italy, Table S2: Summary of the check and cover crop treatments, respective termination methods and cash crop sowing techniques following cover crop termination, for organic corn and soybean grown in two years across different farms in northern Italy, Table S3: Costs of cover crop establishment and termination, inter-row weeding operations, cash crop sowing and additional operations. Average values across the harvesting years 2017 and 2018, Table S4: Corn crop revenues with the traditional weed control technique (inter-row weeding) and with the cover crop techniques. Harvesting years 2017 and 2018, Table S5: Soybean crop revenues with the traditional weed control technique (inter-row weeding) and with the cover crop techniques. Harvesting years 2017 and 2018, Table S6: Mean nitrogen uptake in total above-ground biomass at the vegetative stage V7 and at harvest of corn sown and grown on terminated autumn cover crop treatments as compared to corn sown on tilled soil and subject to post-emergence mechanical inter-row weeding in three organic farms of northern Italy in the second evaluation year (2018).

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